Review on recent results of *J/ψ* production at STAR

J. Mrázková, *for the STAR Collaboration*
(FNSPE, Czech Technical University in Prague)

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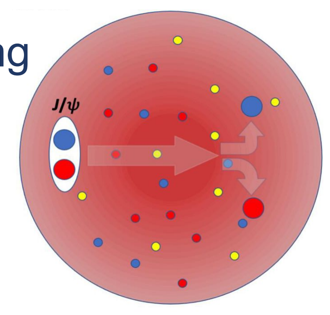
Abstract

The production of *J/ψ* (bound state of charm and anti-charm quark) in proton-proton collisions gives an opportunity to test quantum chromodynamics (QCD) calculations, as the production of *J/ψ* involves both perturbative and non-perturbative processes. However, theoretical calculations are still unable to fully explain experimental results, such as polarization and p_T spectra. More studies are needed to investigate *J/ψ* production mechanism. In heavy-ion collisions, charmonia can be used to study the properties of the medium as they are expected to dissociate in the medium when the Debye radius, inversely proportional to the medium temperature, becomes smaller than their size. Other competing effects, such as recombination, have also been found to modify the observed *J/ψ* yield in heavy-ion collisions. We will review recent measurements of *J/ψ* production in proton-proton and heavy-ion collisions at various collision energies measured with the STAR experiment at RHIC. The data will be compared with recent model calculations on charmonia production.

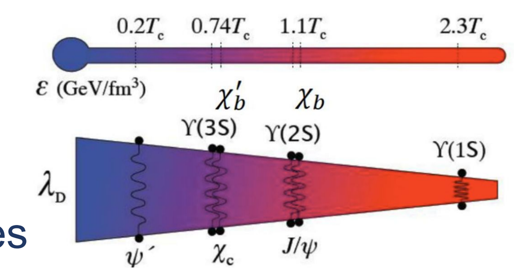
Motivation

Understanding the production mechanisms of J/ψ mesons is crucial for testing QCD calculations in proton-proton collisions and probing the properties of the strongly interacting medium created in heavy-ion collisions.



Credit: Q.Yang (STAR)

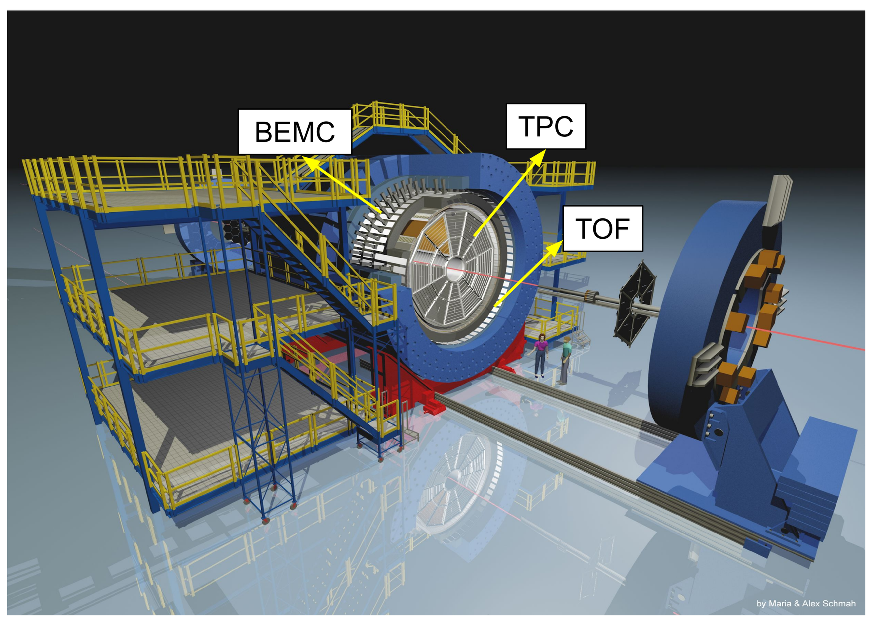
- J/ψ suppression provides evidence of QGP formation, where color screening prevents the binding of charm quarks, depending on the medium's energy density and temperature [1].
- Description of charmonium production in medium is challenging: competing processes of recombination and dissociation



→ Systematic studies across various collision systems and energies may disentangle charmonium production mechanism.

STAR Experiment

Some of the key detectors used in *J/ψ*-related analyses at mid-rapidity:



<u>**T**ime **P**rojection **C**hamber</u>

- Charged particle tracking, momentum and energy loss (PID) measurement

<u>**T**ime **O**f **F**light **D**etector</u>

- Improves particle identification

<u>**B**arrel **E**lectromagnetic **C**alorimeter</u>

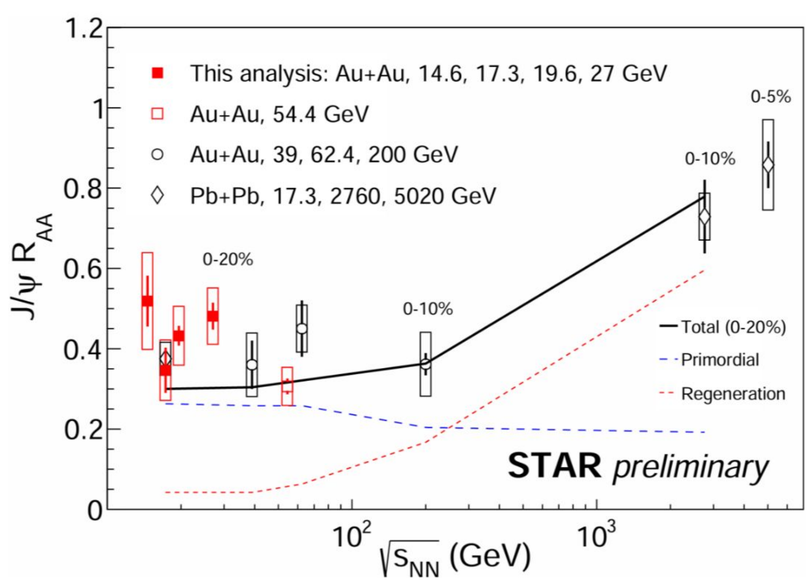
- Particle detection based on deposited energy
- Granularity in (η,φ) = (0.05,0.05)

Full azimuthal coverage: 0 ≤ φ < 2π

Inclusive *J/ψ* R_{AA}

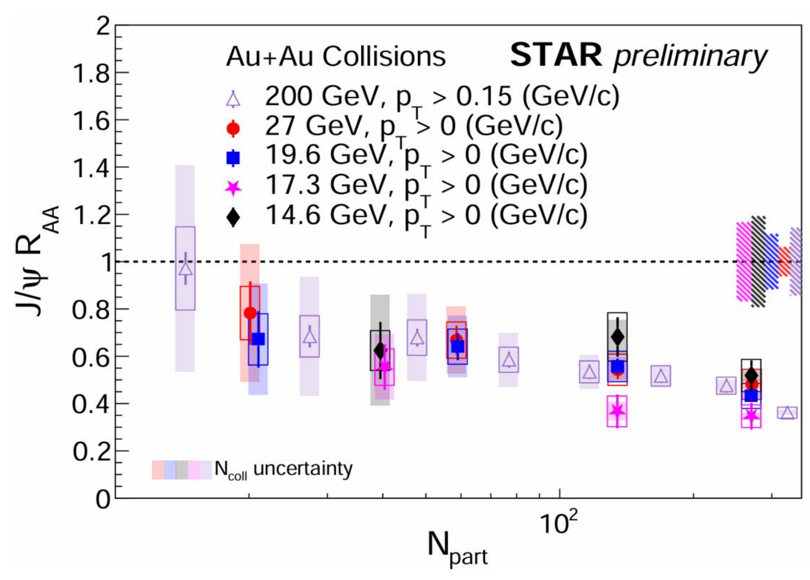
To study the influence of the medium on *J/ψ* production, we can use the nuclear modification factor R_{AA} defined as:

$$R_{AA} = \frac{\sigma_{\rm inel}}{\langle N_{coll}\rangle}\frac{d^2N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$



Energy Dependence

- No significant energy dependence in central collisions within $\sqrt{s_{NN}}$ = 14.6 – 200 GeV is observed [2-4].
- Energy dependence is qualitatively described by the transport model [5,6], with primordial production being dominant at RHIC energies and regeneration at the LHC [7,8].



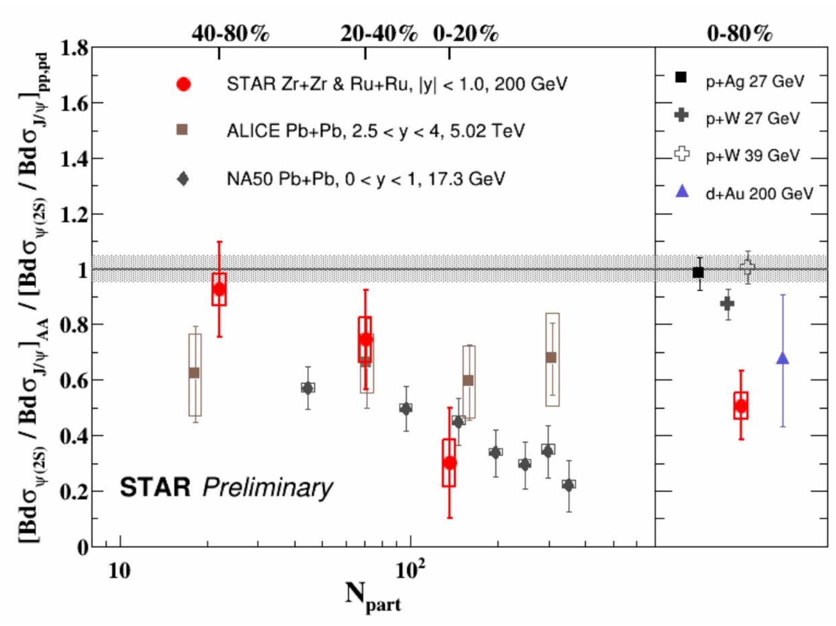
Centrality Dependence

- Hint of decreasing trend in R_{AA} as a function of centrality → stronger suppression of *J/ψ* production
- No significant energy dependence observed for a given $\langle N_{part}\rangle$

ψ(2S) over *J/ψ* Double Ratio

First observation of charmonium sequential suppression in heavy-ion collisions at STAR is shown and quantified by the *ψ*(2S) over *J/ψ* double ratio:

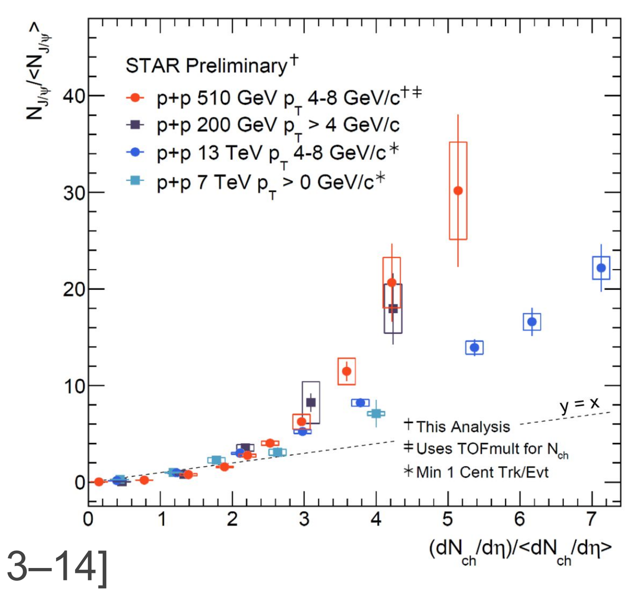
$$\frac{[(B d\sigma_{\psi(2s)})/(B d\sigma_{J/\psi})]_{AA}}{[(B d\sigma_{\psi(2s)})/(B d\sigma_{J/\psi})]_{pp,pd}}$$



- *ψ*(2S) is more suppressed than *J/ψ*, reflecting its weaker binding energy and greater sensitivity to QGP
- Suppression grows with centrality, driven by higher energy density and QGP lifetime in central collisions
- Data are compared with an average p+p reference from NA51, ISR and PHENIX [9–11]
- Double ration is smaller in isobar system than that in p+A system

J/ψ Production vs Multiplicity in p+p

At high multiplicity p+p collisions, MPI and string percolation are expected to influence J/ψ production.



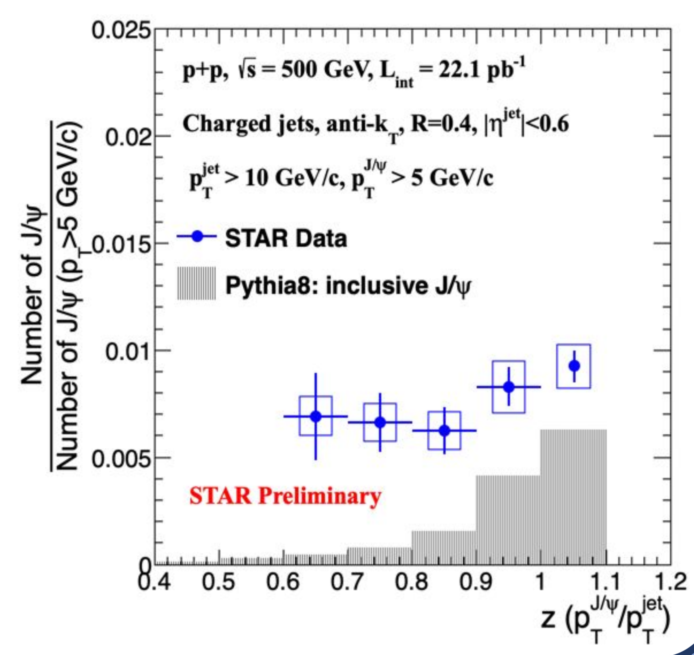
- Compared to previous results at √s = 200 GeV [12], higher range in multiplicity was achieved
- Normalized yields at 510 GeV are consistent with the yields at 200 GeV
- Sign of splitting between RHIC and LHC energies [13–14]

J/ψ Production in Jets

Study of J/ψ production in jets provides additional discriminative power for production mechanisms. The fraction *z* of charged-particle jet transverse momentum carried by *J/ψ* is defined as:

$$z(J/\psi) = \frac{p_T^{J/\psi}}{p_T^{jet}}$$

The *z* distribution for inclusive *J/ψ* in jets in p+p collisions at √s = 500 GeV, normalized by the *J/ψ* cross-section [15], is compared to model prediction (Pythia8):

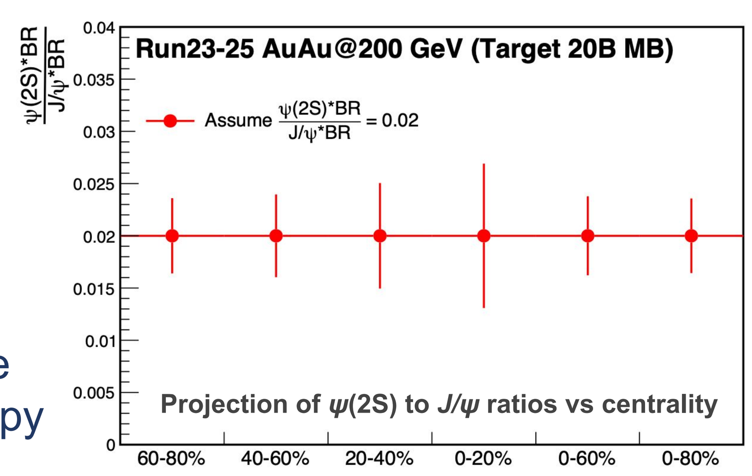


- The results show discrepancy with model predictions.
- The *z* distribution remains relatively flat, while Pythia predicts a steep rise toward *z*=1, where most the jet momentum is carried by the *J/ψ.*

Summary and Outlook

Recent measurements of charmonium production in A+A collisions have been shown, including the study of *J/ψ* R_{AA} and the charmonium suppression using the *ψ*(2S) over *J/ψ* double ratio. The *J/ψ* production dependence on charged-particle multiplicity and its production in jets in p+p collisions at √s = 510 GeV was presented.

Further charmonia measurements have not been covered in this poster, such as study of azimuthal anisotropy and polarization.



- Studies of *J/ψ* polarization in jets in p+p collisions are ongoing to provide deeper insights into the *J/ψ* production mechanism.
- The high luminosity p+p and Au+Au data at 200 GeV from 2023-2025, will enable more precise measurements of *J/ψ* elliptic anisotropy and *ψ*(2S) production.

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